ECE 325, Fall 2015, Test 2

Problem 1 (40 points): Short answer questions

a. (3 points each) True or false for each of the following statements?

1) Analogous to the electrical resistance of a conductor, the magnetic reluctance \( R_m \) of an iron core placed in a varying magnetic field is a constant that is proportional to its effective length and inversely proportional to its effective cross-section area.
   F. (Not constant. Slide #3-6)

2) Magnetic domains of a rotating iron armature placed in a constant magnetic field are always lined up with the magnetic field.
   F. (Not always, depending on \( H \). Slide #3-13)

3) Consider a load coupled to a motor by means of a shaft. The load exerts a constant load torque \( T_L \). When the mechanical torque \( T_M \) developed by the motor and the rotation of the shaft have opposite directions, there must be \( T_M < T_L \)
   F. (When \( T_M > T_L \), \( n \) will first decrease and then reverse the direction. Slide #3-23)

4) Continue with 3). The motor must operate in the generator mode (receiving power from the load).
   T. (Slide #3-24)
5) The voltage regulation of a transformer depends on the power factor of the load on its secondary side. If the load is capacitive, the full-load voltage may exceed the no-load voltage, in which case the voltage regulation becomes negative.

T. (Slide # 4-17)

6) Four base quantities, i.e. $S_B$, $E_B$, $I_B$ and $Z_B$, are required to completely define a per-unit system but a minimum of two need to be independently chosen and can be any two of the four, e.g. $I_B$ and $Z_B$.

T. (Slide # 4-23)

7) With the increase of the length of a transmission line, its resistance, inductance and capacitance all increase.

T. (Note: $X_C$ will decrease but $C$ increases. Slide # 5-6)

8) When the power delivered by an EHV transmission line drops to much less than its surge-impedance load (SIL), a shunt capacitor usually needs to be added to the receiving end to improve voltage regulation.

F. (Shunt reactor. Slide # 5-16)
b. (5 points) A round dish of radius $R$ has even density. It is punched to break up into two shapes: a smaller round dish of radius $r$ and a ring with inner radius $r$ and outer radius $R$. They rotate about their centers. If $r=0.8R$, which shape has a bigger moment of inertia?

Right one is bigger (3 pts)

Reason (2 pts):

\[
J_1 = m_1 \frac{r^2}{2} = m \frac{\pi r^2}{\pi R^2} \frac{r^2}{2} = m \frac{r^4}{2R^2}
\]

\[
J_2 = m_2 \frac{(R^2 + r^2)}{2} = m \frac{\pi (R^2 - r^2)}{\pi R^2} \frac{(R^2 + r^2)}{2} = m \frac{R^4 - r^4}{2R^2}
\]

\[
J_1 = J_2 = m \frac{r^4}{2R^2} = m \frac{R^4 - r^4}{2R^2} \Rightarrow 2r^4 = R^4 \Rightarrow r = 2^{-1/4} R = 0.841R
\]

Only if $r>0.841R$, the dish has a bigger moment of inertia.
(6 points) A single-phase 500V/150V transformer has a rating of 15kVA at 60Hz.

1) On the figure, indicate how to reconnect the terminals to make a step-up autotransformer with 150V primary to 650V secondary (which terminals to be short-circuited and which to connect with the source or load)

2) What is the new rating of such an autotransformer?

Slides # 4-27 & 4-28 (Example 11-2)

1) 3 pts

Method 1:

Shortcircuit X1 and H2, connect X1 & X2 to source and connect H1 and X2 to load

Method 2:

Shortcircuit X2 and H1, connect X1 & X2 to source and connect X1 and H2 to load

2) 3 pts

\[ I_H = \frac{15000}{500} = 30A, \quad I_X = \frac{15000}{150} = 100A \]

New Rating = \( 650 \times 30 = 19.5kVA \)
c. **(5 points)** A power line having impedance $R + jX$ delivers active power $P$ to a load. If the load resistance increases from zero to infinite, the P-V curve about $P$ and the voltage $E_R$ across the load is given in the figure. Which statements are correct?

1) The voltage $E_S$ of the source has a magnitude of 220kV
2) The maximum power the line can transmit is 500MW
3) When the line transmits 300MW power, its voltage regulation is <5%
4) In order to transmit 400MW power while keeping voltage regulation <5%, a shunt capacitor may be added across the load.
5) The transmission line is more like a resistive line than an inductive line

Slides #5-11 & 5-12

1 pt each: 1), 2), 4) are correct and 3) and 5) are incorrect.
Problem 2 (20 points): Draw two equivalent circuits of the transformer respectively referring to the primary side and the secondary side. Determine the values of the components corresponding to $E_g$, $R_1$, $X_{f1}$, $X_m$, $R_m$, $R_2$, $X_{f2}$, and $R$ in each of the two equivalent circuits,

Slide # 4-15

\[ Z_p \quad a^2 \quad Z_s \]
\[ E_p \quad a \quad E_s \]
\[ I_p \quad 1/a \quad I_s \]

\[ Z_p \quad 1/a^2 \quad Z_s \]
\[ E_p \quad 1/a \quad E_s \]
\[ I_p \quad a \quad I_s \]

Draw correct equivalent circuits in topology: 1 pt each

8 values for each circuit: 1 pt each
Problem 3 (30 points): A 3-phase step-up transformer is rated 1500MVA, 11kV/220kV and 60Hz, and has an impedance of 10%. The transformer connects a 3-phase generator rated 11kV to a 3-phase line. If the line transmits totally 900MVA at 240kV with a leading power factor of 0.95. Use the nominal voltage and power as the base quantities.

a. Calculate the per-unit voltage across the load, per-unit voltage across the generator terminals and the per-unit current in the load.

b. Calculate the actual line-to-line voltage across the generator terminals in volt.

c. Calculate the voltage regulation when the load varies between zero and the above load.

Basically the same problem as Example 12-7

a. \( E_B = \frac{220}{1.73} = 127.2 \text{kV} \)

\( S_B = \frac{1500}{3} = 500 \text{MVA} \)

\( Z_T \text{ (pu)} = 0.1j \text{ pu} \)

\( |S_L| = \frac{900}{3} = 300 \text{MVA} \)

\( |S_L| \text{ (pu)} = \frac{S_L}{S_B} = \frac{300}{500} = 0.6 \text{ pu} \)

\( \cos^{-1}(0.95) = 18.2^\circ \)

\( S_L = 0.6 \angle 18.2^\circ \text{ pu} \)

\( E_L = \frac{240}{1.73} = 138.7 \text{kV} \)

\( E_L \text{ (pu)} = \frac{E_L}{E_B} = \frac{138.7}{127.2} = 1.091 \text{ pu or } = \frac{240}{220} = 1.091 \text{ pu} \)

\( I_L \text{ (pu)} = \frac{(S_L/E_L)}{*} = 0.55 \angle -18.2^\circ \text{ pu} \)

\( E_S \text{ (pu)} = E_L \text{ (pu)} + I_L \text{ (pu)} \times Z_T \text{ (pu)} = 1.109 \angle 2.7^\circ \text{ pu} \)

b. \( E_g = E_S \text{ (pu)} \times 11 = 12.2 \angle 2.7^\circ \text{ kV} \)

c. \( VR = \frac{(|E_S| - |E_L|)}{|E_L|} = \frac{(1.109 - 1.091)}{1.091} = 1.65\% \)
Problem 4 (20 points): The voltage phasor of regions a and b and the reactance of their tie line are given in the figure. Calculate

a. The power transmitted by the line and the direction of the power flow
b. If a phase-shift transformer is used to make the line transmit 100MW more in the original direction of the power flow, what is the requested phase shift?

Slide #5-12 (similar to Example 25-8)

\[ P = \frac{|E_S| |E_R|}{X} \sin \delta \]  
(Take 1pt if \( P = \frac{E^2}{X} \sin \delta \) is used)

a. \( P_{ab} = 100 \times 105 \times \sin(30^\circ)/10 = 525 \text{MW} \)  
   10 pts

b. \( P_{ab\text{new}} = 100 \times 105 \times \sin(\theta)/10 = 625 \text{MW} \)  
   \( \theta = 36.53^\circ \)  
   10 pts

\( \Delta \theta = 6.53^\circ \)